ATTENTION WAVES AS A MEANS OF MEASURING FATIGUE.

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Early in 1902 the work of Dr. Slaughter and of Mr. Taylor,[1] and in particular the first paper of Wiersma,[2] upon the influence of short periods of work on the fluctuations of the attention, suggested that the same method might be applied to comparing the condition of fatigue at different times of the day. As the writer found himself compelled to do an unusual amount of teaching in the second semester of that year, it seemed that some interesting results might be obtained by taking a record of the attention waves in the morning just after beginning work, and in the evening before dinner. While living in Würzburg the following summer the records were continued, through the kindness of Professor Külpe, who placed his laboratory at the writer's disposal. Later, Professor Külpe volunteered to take a day's record. Again, after returning to America last fall, the writer continued the experiments upon four men.

Wiersma's second article,[3] which anticipated our results so far as experiments upon the daily rhythm of the attention waves is concerned, was received after our preliminary experiments were well under way. It nevertheless appeared to be worth while to continue the investigation, as Wiersma's results were obtained from but few persons and covered but three days. Then, too, he paid no attention to the length of the wave, and one of the main purposes of the present investigation was to discover if the waves had a daily rhythm in length that is analogous to the diurnal change in the rate of most physiological rhythms.

The apparatus used here consisted of a long horizontal drum,

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[1] *Am. Jour. of Psych.*, March, 1901.
[2] *Zeitschr. für Psychologie*, XXVI, p. 168.
[3] *Ibid.*, XXVIII, p. 179.

with the carrier for the time-markers driven by an endless screw. The drum, when moving at a rate of a centimeter to the second, gave an unbroken record for 14 minutes. The drum was driven at a constant rate by an electric motor, but as a further precaution, and for convenience in reading, the time was recorded by a Jacquet chronograph, which wrote fifths of seconds. The observer sat in the dark room facing the Masson disk, and at a distance of 55 cm. from it. The disk was illuminated by a 16 c. p. lamp at a distance of 20 cm. and carefully screened from the eye of the observer. When the writer was subject no experimenter was present. The motor was started by reaching from the dark room after everything had been made ready and the record continued until it seemed that sufficient time had elapsed to fill the drum. The disk was the same for all subjects except P. and gave a ratio of black to white of $\frac{1}{32}$, for P. $\frac{1}{40}$.

In Würzburg the waves were written upon the Zimmermann kymograph with the automatic lowering device. The apparatus was set up in the darkroom; the disk, at a distance of 140 cm. from the observer, was illuminated by a Welsbach lamp. During a large number of experiments Professor Külpe took charge of the apparatus.

When the records of Dr. Wallin and Mr. Freund were taken the drum used for the other experiments here was required for another investigation, so that it was necessary to use a simple kymograph. This was the least satisfactory of any of the methods employed, as the rate was so slow that only seconds could be recorded, and in reading, these must be estimated to tenths.

The observers were Professor Külpe (K.), Dr. Wallin (W.), Mr. Hayden (H.), Mr. Galloway (G.), Mr. Freund (F.), and the writer (P.).

The investigation furnishes material for the discussion of three problems: (1) the degree of fatigue at different times in the same day as influenced by the amount of work that has been performed, and by the type of the individual; (2) the course of the fatigue that is induced by the work of recording the attention waves as affected by the time of day, and (3) the fluctuation in the length of the total wave with the time of

day. Instead of always taking records of the same length, as Wiersma did, and using the total period of visibility or invisibility as the measure, we permitted the length of the record to vary, within limits, and used the ratio between the period of visibility and the period of invisibility as the index. In working up, the curves were divided into five or six equal divisions, and each part was averaged separately first, and then these several sums were added and treated as wholes. In preparing the tables for publication, the corresponding times of the days that were of the same character are averaged together. Except for *G.* and *F.*, each day's curves showed the same tendency as the average. It seems hardly worth while to take the space to give the results for each day, and the average is a fairer way to represent the results as a whole, than to select sample days.

Experiments were usually made about 9.00 A. M., at noon, just after the noon-day meal, and in the evening. The tables show that we may divide our subjects into four distinct groups. *K.* is a typical evening worker. There is a progressive increase in his ability to see the gray ring from the first experiment in the morning, throughout the entire day. It is true that we have but a single day's results, but Professor Külpe had worked with Lehmann and others in the early investigations at Leipzig, and was a highly trained observer in work of this kind.

P. and *W.* are just as typical morning workers. Both show a continuous increase in capacity up to the evening curve, with a decrease in that. *W.* is particularly interesting for us, because his fluctuations are of very short period, and for the most part correspond in length to the respiratory rhythm, with only an occasional longer wave. His results show that attention waves of this type can also be used to discover the status of fatigue of the individual. *F.*, too, is probably of the morning type, both from what he says of his habits of work and from our records. One day's evening record, however, is inconsistent with this statement; the ratio of visibility to invisibility rises from 1.50 in the morning to 5.08 at 6.00 in the evening, without anything in the records of the daily routine to account for it. On the other two days, and in the average, his results agree with his statement of his methods of work.

TABLE I.

K. August 11, '02.

Time of Day.	No.	m V	m I	$\frac{V}{I}$	Sum.
9.00- 9.30	38	7.8	5.7	1.6	13.5
12.00-12.45	42	9.5	4.9	1.9	14.4
2.55- 3.10	41	11.3	3.3	3.4	14.6
6.00- 6.22	33	16.4	2.9	5.6	22.0

The column headed *No.* gives the number of waves measured; that headed *m V* the mean of the periods during which the ring of the disk was visible; that headed *m I* the mean of the periods during which it was invisible; that headed $\frac{V}{I}$ the ratio of these two periods; and that headed *Sum* or $V+I$ the total length of the attention wave. The lengths are given in all cases in seconds.

TABLE II.

G.

Time.	No.	m V	m I	$\frac{V}{I}$	V+I
Morning 9.00	249	4.8	4.1	1.17	8.9
Noon	181	5.1	3.8	1.35	8.9
After Dinner	265	4.8	4.1	1.17	8.4
Evening	377	4.6	3.8	1.21	8.4

TABLE III.

H.

Time	No.	m V	m I	$\frac{V}{I}$	V+I
Morning	287	7.3	2.1	3.43	9.4
Noon	230	6.3	2.4	2.63	8.7
1-2 P. M.	285	7.2	2.1	3.35	9.3
Evening	300	6.7	2.3	2.94	9.0

TABLE IV.

W.

Time	No.	m V	m I	$\frac{V}{I}$	V+I
Morning	275	3.3	2.1	1.55	5.4
Noon	196	3.9	2.4	1.64	6.3
Evening	281	3.0	2.1	1.46	5.1

TABLE V.

F.

Time	No.	m V	m I	$\frac{V}{I}$	V+I
Morning	73	15.5	3.4	5.03	18.9
Noon	37	15.0	3.2	4.66	18.2
1 P. M.	79	10.9	2.5	3.44	13.4
Evening	63	15.4	3.4	4.53	18.8

H. belongs to neither of the Kraepelin groups, but has two maxima and minima each day. He both tires very quickly and recovers very quickly, so that his morning and his early afternoon records are alike, and his noon and his evening records. The rest at noon, without sleep, almost completely removes all evidence of his morning's work. This result agrees fully with his own statement, made before the curves were worked out.

G. is entirely irregular. His capacity varies differently for different days, and in the average it would seem that his morning and evening conditions are very much alike. He had not noticed any particular difference in the ease of work at the various times of day, so that even in this case there would be no lack of harmony between the results of the records and the man's own account of his working habits. It is to be remarked that *F.* and *G.* are the youngest of the persons experimented upon, and it would be quite in accordance with

Wiersma's results to assume that they had not yet acquired fixed periods of work.

The only chance to study the influence of different kinds and amounts of work is offered by *P.*'s records. All the others were taken on days of about the same routine, or at least the differences are not sufficient to render a decision certain. The records from *P.* cover three distinct kinds of life. Four records were taken on days when he was engaged in teaching from seven to nine hours a day. This work was usually divided into three hours lecturing, two hours of discussion in seminary classes, and from two to four hours of directing laboratory work with classes large enough to engage his attention pretty thoroughly throughout the time. The physical exertion of talking and standing, with the mental work involved, usually left a feeling of exhaustion at the close of the day. Three records were from days during vacation, which were spent in writing three to five hours of the day, with an hour or so of exercise a little before the evening test was taken. A comparison of the records in Tables VI and VII, shows that on the average there is a decided advantage in the evening records of the easier days, and that, too, in spite of the fact that the morning tests show a much greater capacity on those days than on the hard working days. One would expect that it would be much more difficult to produce a decline in efficiency of one half when the efficiency was already low, than when it was comparatively high. The records of March 25 were unusually high as compared with other days of the hard working period. Examination showed this to correspond with the fact that the entire morning of that day was spent in laboratory work, instead of two hours in the laboratory and two in lecture, as on the other days. Evidently, then, so far as can be judged from a single day, lecturing is more fatiguing than the direction of laboratory work, and this result probably corresponds with the experience of most men.

One record, taken during the vacation period, was found to have been made on a day of more than usual indulgence in physical exercise. An afternoon was devoted to golf, and it was entered upon the record that the subject had begun to give out and to play badly before the end of the last round. As

TABLE VI.

P. Hard Days, Mch. 26, 28, Apr. 10, May 1, '02.

Time	No.	m V	m I	$\frac{V}{I}$	V+I
Morning	145	9.8	3.6	2.52	13.4
Evening	230	4.4	3.6	1.23	8.0

TABLE VII.

P. Vacation Period, April 11, 15, 16.

Time	No.	m V	m I	$\frac{V}{I}$	Sum.
Morning	116	11.3	2.7	4.10	14.0
Evening	163	7.7	3.1	2.88	10.8

TABLE VIII.

April 17. Physical Fatigue.

Time	No.	m V	m I	$\frac{V}{I}$	V+I
Morning	42	16.5	2.9	4.10	14.6
Evening	58	4.6	1.9	1.61	6.5

TABLE IX.

P. March 25, '02.

Time	No.	m V	m I	$\frac{V}{I}$	V+I
Morning	22	11.7	2.9	4.10	14.6
Evening	38	9.6	3.0	3.20	12.6

will be seen in Table VIII, there had been a decline in the ratio of the attention wave from 4.10 to 1.61, as compared with 4.10 and 2.88 for the moderate days.

A comparison is also possible between the days of the quiet

TABLE X.

P. April 7, '02.

Time	No.	m V	m I	$\frac{V}{I}$	V+I
Morning	37	14.3	2.6	5.85	16.9
Evening	51	8.4	3.0	2.77	11.4

TABLE XI.

P. July 11-19, '02.

Time	No.	m V	m I	$\frac{V}{I}$	V+I
9.00-10.00	300	6.8	2.8	2.43	9.6
11.30-12.00	245	6.1	2.4	2.51	8.5
3.00-4.00	337	5.9	2.3	2.56	8.2
6.00-7.00	365	5.1	2.4	1.62	7.5

TABLE XII.

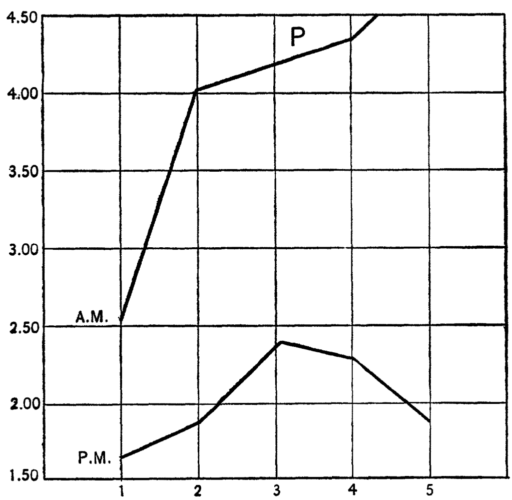
P. July 17. Slept between 2 and 3.

Time	No.	m V	m I	$\frac{V}{I}$	V+I
9.00-9.20	58	5.38	2.23	2.41	7.61
3.05-3.35	63	4.93	2.25	2.19	7.18
6.15-6.40	73	5.05	2.39	2.32	7.44

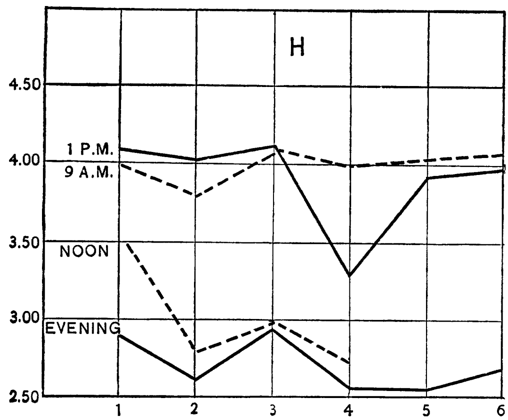
life in Würzburg and the more active life here. While in Würzburg the mornings were usually spent in attending two or three lectures at the university, and in working on curves. The afternoons were devoted to working on the curves, or to an occasional short walk. While the results are not strictly comparable, both because the disk used had a ratio of black to white of $\frac{1}{45}$, as compared with $\frac{1}{40}$ here, and because of the different distance and illumination of the disk, nevertheless the ratios between morning and evening results may be com-

pared. It will be seen from the tables (VI-IX as compared with XI) that the difference for the two periods corresponds closely to the nature of the work done. One day, July 17, shows another form of correspondence. Contrary to the usual habit, an hour's sleep was indulged in on that day between the afternoon and evening records. As a result it will be seen, Table XII, that the evening record is very nearly like the morning record, more like it, in fact, than the afternooon record. So far, then, as our results show anything at all as to the relation between the amount of work and the ratio of the period of visibility to invisibility, there is an inverse relation, as would be expected from theorytical considerations.

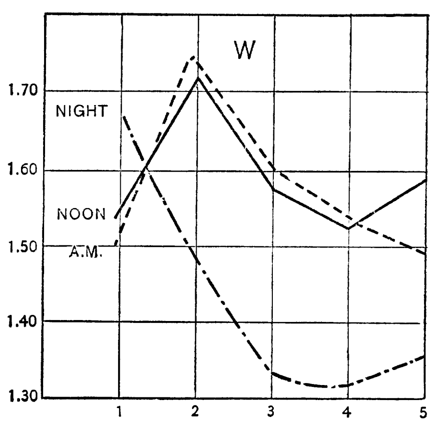
If we divide the series taken at any time of day into smaller portions, and average each part separately, it will be possible to study the advance of fatigue during any one of the daily periods. The results from *G.*, *H.*, *W.*, and *P.*, are susceptible to this form of treatment. The results from *F.* were in too short series to make this consideration possible, as were also all the results obtained in Würzburg. *G.*'s curves show as little change in this respect as in the daily rhythm, however, and so may be omitted from consideration. The results from the other three men are plotted and shown in the figures below. It will be seen that the results here, harmonize in every way with those of the period as a whole. For *P.* there is a constant in-



crease in efficiency in the morning curves, while in the evening the initial increase, due to exercise, is soon followed by a decline. For *H.* the early morning and afternoon curves are



pretty well sustained except for fluctuations throughout. If the fluctuations have any meaning, they would mean an initial decline before the warming-up process begins, then a second fatigue period, followed in turn by catching the "second wind," which results in making the beginning and the end of the curve very much alike. In the evening curves the minor fluctuations show themselves to a slight extent, but are entirely overshadowed by the continuous decline. *W.*'s two morning



curves are almost identical, a long warming-up period followed

by a longer decline. The evening curve, on the contrary, shows a marked decline throughout. In all, however, we find exactly what we should expect from the other tables, that the periods of general fatigue are accompanied by rapid exhaustion, while the period of increasing efficiency due to exercise (*Uebung*), so prominent in the rested condition, rapidly disappears.

The third question in mind when the investigation was begun was whether the length of the attention wave as a whole, the sum of the visible and invisible periods, had a regular daily variation. Dr. Slaughter found that the attention wave corresponded in length to the Traube-Hering wave of blood pressure. His results have recently been confirmed by Bonser in ignorance of the existence of the earlier work. If the hypothesis be true that there is a real connection between the two, it would seem probable that the attention wave has a diurnal variation, as have the pulse and respiratory rhythm. The last column in each of the tables brings together the evidence on this point. It will be seen that for all the different persons the greater length of wave corresponds to the time of greatest attention efficiency. For the morning workers there is a constant decrease in the length from the morning through to evening, while *K.* shows an increase in length between morning and evening. *H.* again shows the longest waves early in the morning and in the afternoon, with a shorter one at noon and night. The difference for *F.* is very slight on the average, so slight that taken alone it could have no meaning. This, however, is due to exceptionally long waves on the day when he showed his greatest efficiency in the evening. *G.*, on the other hand, joins the ranks of the morning workers in this respect, and shows a considerable quickening of the rate in both the afternoon series. It might seem strange that *W.*, whose attention wave more nearly corresponds in length with the breathing rhythm, should show the same daily variation as the individuals whose waves are of the Traube-Hering type. But it must be remembered that the breathing is also normally quicker in the evening, and the pneumograph records taken at the same time as the attention waves shows that the normal quickening occurs in his case. As *W.*'s attention wave is in part the cor-

relate of the Traube-Hering, in part of the respiratory, rhythm, so the quickening is probably due partly to the change in each.

In an investigation soon to be published, Mr. Galloway has found that the Traube-Hering waves actually show a diurnal periodicity, corresponding to that here noted in the attention waves. That the attention waves and the vaso-motor waves have the same daily variation, adds another link to the chain of evidence that the two have the same physiological basis.

We can explain our results if we consider the fluctuations of the attention a resultant of two physiological processes, of the degree of efficiency of the cortical cells, on the one hand, and of the state of excitation of the vaso-motor center on the other. The reinforcement from the medullary center would have its effect in decreasing and increasing the response of the cells, and would determine the rate of the fluctuation, but the proportion of the cycle in which they would be sufficiently effective to give rise to a sensation, would depend primarily upon the freshness of the cells themselves. The degree of efficiency of the cells, then, would be measured directly by the ratio of the period of visibility to the period of invisibility of our minimal stimuli, while the length of the total wave would be a measure of the length of the Traube-Hering wave.

In conclusion, I desire to express my thanks to the persons who so kindly gave their time to the work, and particularly to Professor Külpe, both for the facilities of his laboratory, and for his advice and encouragement, as well as active co-operation in the work.